TriBot : Search And Rescue Robot

By

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FINAL REPORT

Submitted to the Electrical & Electronics Engineering Programme
in Partial Fulfillment of the Requirements
for the Degree
Bachelor of Engineering (Hons)
(Electrical & Electronics Engineering)

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CERTIFICATION OF APPROVAL

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Approved:

Patrick Sebastian
Project Supervisor

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TRONOH, PERAK

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CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

Khairul Shariman Bin Kalid

ABSTRACT

In this new era where robotics plays important role in performing dangerous task previously performed by human such as disabling bomb, handling hazardous material and even helping in search and rescue mission. Collapsed buildings are the most unstable place to perform search and rescue mission by human where the weight and size limits the rescuer movements. Sudden movement will cause further damage to the victims who trapped in the rubble and also to the rescuer. Robot with conventional locomotion seems to be not suitable to navigate on uneven and unstable terrain. This project describes the development of a search and rescue robot with non-conventional locomotion which is used to help first responder (Fire Fighters, Police and Medical) in a search and rescue mission on uneven and unstable terrain to determine the location of the victims in confined places such as collapse buildings without causing further damage to the victims and the rescuer. The robot that will be developed is a non-conventional locomotion robot where it have three arms that enable it to move by dragging itself forward, backward, left and right. It should able to move on unstable and difficult terrain and also able to climb stairs. Extra features such as camera, microphone, speakers and other features could be added according the needs of the project. Robots will be a valuable asset in the near future for search and rescue teams from around the world. This project is based on robot that have been developed named TerminatorBot by Associate Professor Richard M. Voyles from University of Denver.

ACKNOWLEDGEMENTS

First of all, I would like to thank God, for giving me the strength and health to do this project work until it done. I would like to show my gratitude to my final year project supervisor, Mr. Patrick Sebastian for supporting and guiding me throughout this project. His advices and ideas are very helpful in completing this project. Not forgotten to my family for providing everything, such as money, to buy anything that are related to this project work and their advise, which is the most needed for this project such as Internet, books, computers and all that as my source to complete this project. They also supported me and encouraged me to complete this task so that I will not procrastinate in doing it. I am indebted to my many of my colleagues to support me and giving me ideas on this project.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1
INTRODUCTION

In this advance modern world with advance technologies, robotic plays important part in any types of industries such as in automotive industry, medical industry and even commercialized robots such as "Roomba" a robotic vacuum cleaner and "Asimo" a humanoid robot that able to greet and perform simple tasks. In search and rescue mission, robot is needed to help first responder to navigate on unstable structure before they step in to save the victims and not all robots with conventional locomotion such as using wheels or chain wheel are able to navigate on unstable structure. In this project, alternative locomotion are researched and developed for different types of surfaces such as flat surface, rough surface, uneven surface and also unstable surface suitable with the application in search and rescue mission.

1.1 Problem Statement

In this project, four main problem have been identified which are method of locomotion of the robot, the speed control for the robot locomotion, testing of the robot and finally adding extra features to the robot. The robot needs to have its own method of movement to navigate itself to move left, right and climbing. If this problem is not solved, the robot may not able to turn left, right and climbing. Thus, it will affect the overall status of this project. Second problem is to be able to control the speed of the robot movement. Even though this is not a major problem, it still will affect the end user to have total control the robot. Precision and fast movement will have added value to the robot for search and rescue mission. Next problem is to conduct tests for the robot where it needs various types of tests so that any defect can be detected earlier. Finally the last problem identified is the features to be added to the robot (ie: camera, microphone, speaker, auto navigation) It affects the overall search-and-rescue purposes where extra features such as camera are needed to enable the rescuer to have clear view of location where the robot moves. Microphone and speaker will help the rescuer to communicate with the victim to be rescued or listen for sounds of potential survivors in the rubble. For real application on site, it needed to be as small and compact as possible so that the robot can navigate in tight places.

1.2 Objective

Objective of this project is to design and build a three-limbed robot that uses non-conventional locomotion to move on any uneven surface where its main application is to assist rescuer in any search and rescue mission to verify the location of the victims in confined places such as collapse buildings and aftermath of natural disaster.

1.3 Scope of Study

This study is combination of several areas of engineering which are Electrical and Electronic design, Embedded Software development and Mechanical design. Electrical and Electronic design is applied when designing the circuit for the robot limbs that uses servo motor and the microcontroller. Embedded Software is applied to design the movement of the robot's arms. How the robot moves and how the microcontroller controls the robot movements will be specified in the embedded coding using C language and libraries for the microcontroller. Mechanical design is applied to design the arms and the body for the robot. The arms will give the ability to moves while the body of the robot provides compartment to store the electrical and electronic parts. This area of engineering is very useful in robotic development. By combining all three areas of engineering, developing a prototype for the search and rescue robot can be successfully archived

CHAPTER 2
LITERATURE REVIEW

In this chapter will explain about the review on thesis and journal that have been done which related to understanding the nature of non-conventional locomotion. Thus, enable to develop TriBot the search and rescue robor.

2.1 TerminatorBot

TriBot: Search and Rescue robot is based on research and development of TerminatorBot or CRAWLER as shown in Figure 1 – Locomotion and Manipulation from a Single Mechanism done by Associate Professor Richard M. Voyles from University of Denver.[1] The CRAWLER is acronym for Cylindrical Robot for Autonomous Walking and Lifting during Emergency Response. His project, CRAWLER or The TerminatorBot is intended for military and civilian surveillance and search-and-rescue applications. It is a small cylindrical shaped robot (75mm diameter) with two, three-degree-of-freedom retractable arms.[3] It uses crawling movement to move over any difficult terrain as shown in Figure 2.[2] A.P Richard M. Voyles get his inspiration to develop CRAWLER from final scene of the *Terminator* movie. His two long-term goals regarding size the TerminatorBot. First is to shrink the robot to half its original size so that it can be transported to hazardous sites using a M203 grenade launcher and second goal is to increase its size so that it can achieved better power-to-weight ratio. He also plans to examine the transition from crawling to bipedal walking using another set of arms for specific functions. [4]

For the TriBot project, there are several aspects need to evaluate. First is the type of locomotion the robot need so that the robot can navigate on any terrain without any problem. Currently, there are two methods for the robot locomotion. First method is by moving all three arms at once to drag its body to move forward or backward and for turning left or right, one arm move backward and another arms move forward. The second method is to move each arm one-by-one to move forward or backward and the most left or right arm hold to the ground while other two arms move forward or backward for the robot to move left or right. The methods mentioned above need to be tested for its capability to perform its intended locomotion which is dragging method. Second aspect is the materials, components, and microcontroller to be use. For microcontroller, it is suitable to use Arduino Duemilanove Microcontroller board. This is because it has six PWM pins which is equivalent to the number of servos used. It uses low DC voltage as the lowest input which is 5V and the maximum DC input is 12V. Other specification of the microcontroller will be explained in the result and discussion section and same goes to material and components.

Based on the review, it shows that the TriBot is possibly to be a working robot that moves using dragging type of locomotion where it drags its body using its three two-jointed arms. The concern that need to be kept in mind is that the method on how the robot navigate to the left and right need further investigation when the prototype is build.

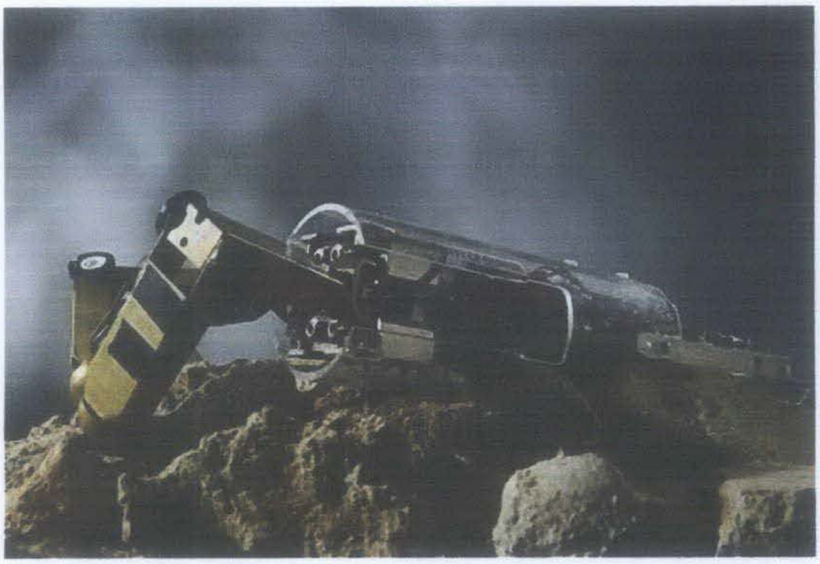

Figure 1: TerminatorBot/CRAWLER

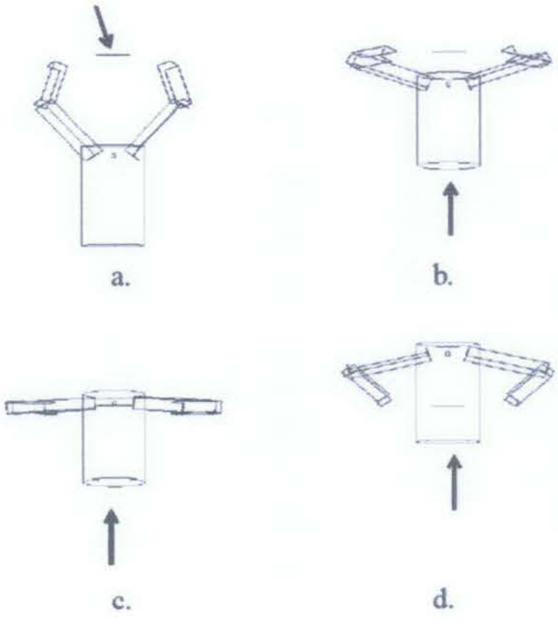

Figure 2: Top View of TerminatorBot locomotion start from (a) to (d)

CHAPTER 3
METHODOLOGY

This chapter presents the research method, study area and prototyping material to produce the prototype of TriBot: Search-and-Rescue robot.

3.1 Procedure Identification

This study will make use of the Information Resource Center in search for information on robotic locomotion and the foundation for mechanical design. Trial-and-error method will be applied for perfecting the movement of the robot where any modification on the embedded coding can be done after testing the prototype.
Figure 3 shows the procedures that have been done previously for developing the robot in the first phase of this project:

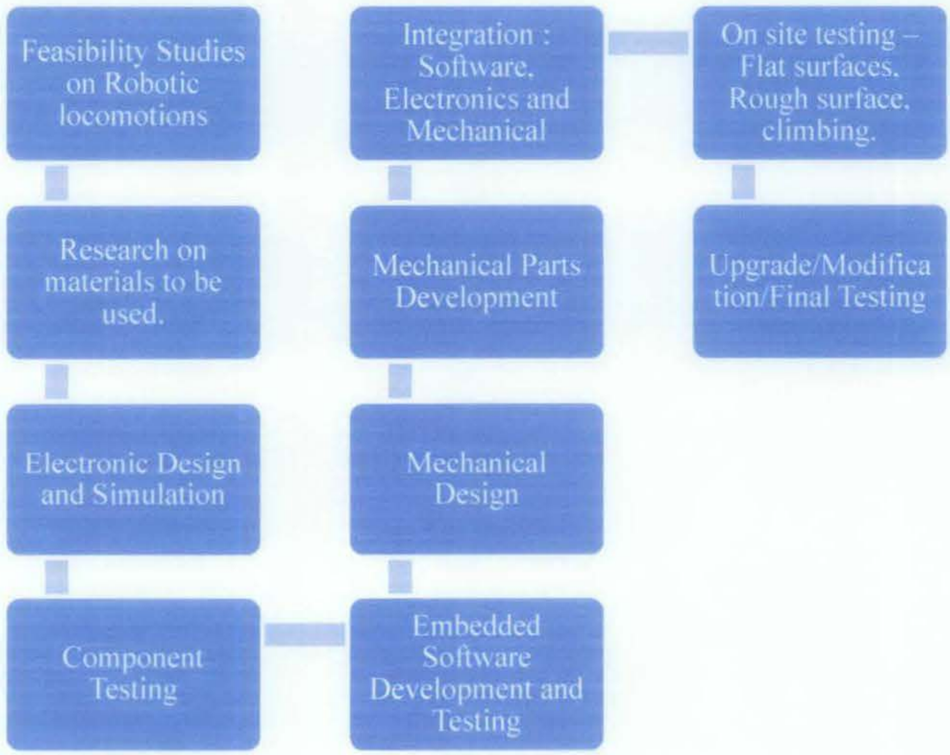

Figure 3: TriBot Phase 1 Development Process

The procedure starts with feasibility studies on how robot moves from one location to other location. In robotic, engineers need to design their robot so that it is suitable for the robot movement or in other name "locomotion" to its application. Then the process goes to research on the components to be use in the robots, based on the research from the feasibility studies, material that need to be use can be roughly determined such as mechanical parts, electronic parts, tools and equipments. Then, electronic design can be made to design the hardware part of the robots. Then the design is verified using simulation software. Next the electronic components are tested using electrical measuring equipments such as multimeter and oscilloscope. After the components have been tested, the embedded software development can be start. To test the coding, the sketches need to be injected into the microcontroller and the output of the microcontroller will be as per designed. Mechanical design comes next where the casing and other mechanical part are designed using CAD software before the mechanical part of the robot is build. Then the outputs from electronic, mechanical and embedded software are integrated into one robot prototype. The prototype is then being tested its locomotion on different terrains. Based on the result, adjustments or modification can be made to enable the robot perform as per designed.

Figure 4 shows the procedures for developing the robot for the second phase of this project (Current phase):

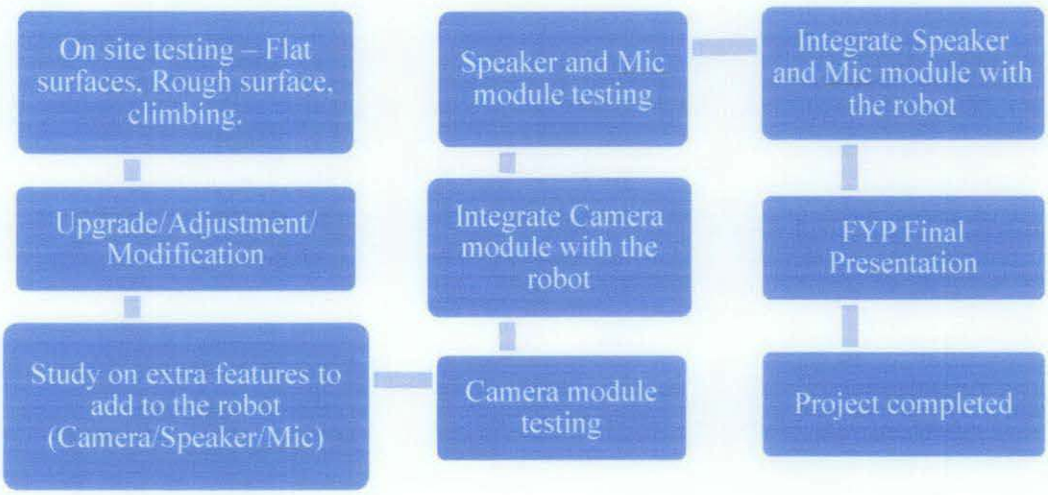

Figure 4 : TriBot Phase 2 Development Process

For the second phase of this project, extra features are implemented to the robot. Current progress is in upgrade and modification of the robot movement where based on the previous test as shown in Figure 4, the robot need to have improvement on navigating left and right. Where jointed brackets are installed to the arms and extra servo motor is added to move the arms left or right. The extra feature such as camera with building microphone is still in the fundamental studies phase. Until the locomotion of the robot is not perfected, the extra features are kept in view.

3.2 Study Area

This project combines three areas of engineering which are Electrical and Electronic, Embedded Software and Mechanical. For Electrical and Electronic area, it is more to designing the circuit for the robot. Embedded software area applies in developing the coding in C language for the microcontroller to control the robotic movement or locomotion. Finally in mechanical area applies in designing and producing the casing and other mechanical part for the robot ruggedness. Figure 5 shows the relationship between the input and the output.

Figure 5: Theoretical method for integrating Input and Output

3.3 Tools and Equipment required

This section shows the list of materials and components used in producing the prototype for TriBot.

3.3.1 Electronic

1. Arduino Duemilanove Microcontroller (ATmega328 Microprocessor)
2. Servo Motors
3. Force Sensors
4. Multiple core wires
5. Potentiometers/Joystick
6. Resistors, capacitors and voltage regulators
7. Testing Tools: Multimeter

3.3.2 Software

1. Arduino 0018: Compiler for Arduino Microcontroller
2. Pspice (Electronic circuit design),
3. Autocad (Mechanical design)

3.3.3 Mechanical

1. Plastic Box (Robot casing/housing)
2. Aluminum Brackets (For robotic arms)
3. Shearing Machine
4. Cutting Machine
5. Drilling Machine

CHAPTER 4
RESULTS AND DISCUSSIONS

This chapter will explain the testing, measurement and observation that have been done during the development of TriBot. It will also discuss on the methods of locomotion for TriBot.

4.1 Results

In this section, the results for testing that has been done on electronic parts, embedded software mechanical design and the robot locomotion. Figure 6 below shows the block diagram for TriBot.

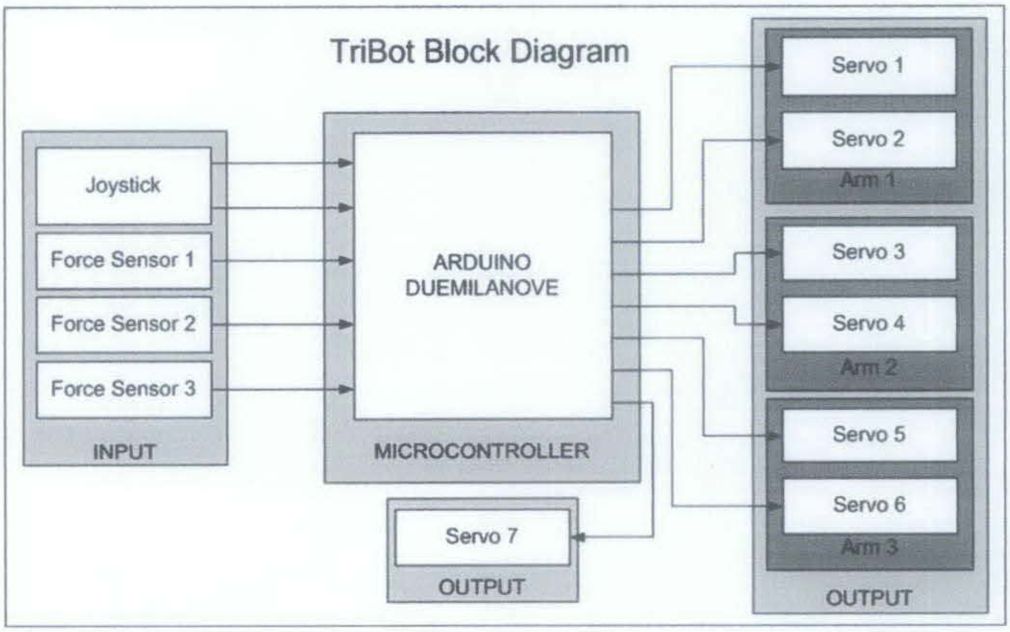

Figure 6: TriBot Block Diagram

4.1.1 Electrical/Electronic testing

This subsection will explains the testing done on electronic components, measurements and the specification details on components to be use. The electrical and electronic components that have been tested are the Arduino Duemilanove Microcontroller, Servo motor, two-axis Joystick and the power supply management.

4.1.1.1 Arduino Duemilanove Microcontroller

The Arduino Duemilanove as shown in Figure 7 is a microcontroller board that uses an Atmel microprocessor which is the ATMega328. It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 16 MHz crystal oscillator, a USB connector, a power jack, an ICSP header, and a reset button. It contains everything needed to support the microcontroller by simply connect it to a computer with a USB cable or power it with an AC-to-DC adapter or battery to get started [5].Table 1 shows the technical specification of Arduino Duemilanove board. Refer to **Appendix A** for Arduino Dueminalova schematic.

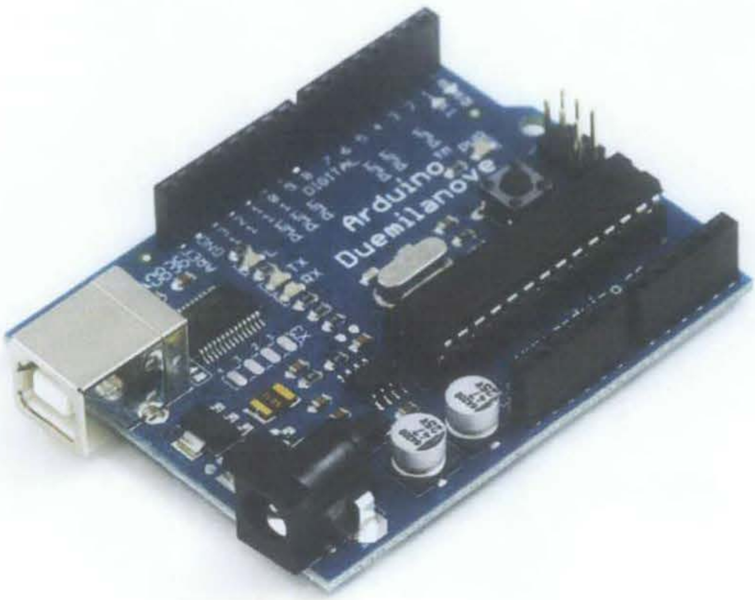

Figure 7: Arduino Duemilanova Board

Table 1: The specification of Arduino Duemilanova Microcontroller

Parameters	Value
Microcontroller	ATmega328
Operating Voltage	5V
Input Voltage (recommended)	7-12V
Input Voltage (limits)	6-20V
Digital I/O Pins	14 (of which 6 provide PWM output)
Analog Input Pins	6
DC Current per I/O Pin	40 mA
DC Current for 3.3V Pin	50 mA
Flash Memory	32 KB of which 2 KB used by bootloader
SRAM	2 KB
EEPROM	1 KB
Clock Speed	16 MHz

4.1.1.2 *Servo Motor*

Servo motor as shown in Figure 8 is used in this project is a standard 4Kg.cm torque with 4.8V to 6.0V of operating voltage. Table 2 below shows the specification of the Servo motor.[6]

Figure 8 : Servo Motor

Table 2: Servo specification

Specification	SV01 Model
Gearbox	Plastic
Torque at 4.8V	4.0Kg.cm
Torque at 6V	4.5Kg.cm
Operating Voltage	4.8-6.0V
Operating Frequency	40Hz
Moving Range	0^{O} - 180^{O}
Speed	0.21 sec/60^{O}
Signal to control Angle	TTL PWM
PWM at min angle	0.5ms
PWM at max angle	2.5ms
Wiring (Brown wire)	Ground
Wiring (Red wire)	4.8-6.0V
Wiring (Orange wire)	PWM signal
Dimension	41mm x 20mm x 37mm
Weight	40g

4.1.1.3 Two-Axis Analog Joystick

The joystick uses a potentiometer for each axis as shown in Figure 9. The potentiometer has three pins which is uses for voltage supply, ground and the output. Measurements have been made to determine the value of resistance at one end, center and the other end and also their respecting voltage. Table 3 shows the result on the measurements that have been done.

Figure 9: Two-Axis Joystick

Table 3: Two-Axis Joystick specification (Measured)

Two-Axis Analog Joystick Specification	
Pin Configuration	
0	Y-Axis
1	X-Axis
6	Voltage Supply (5V)
7	Ground (0V)
Measurement	Value
V_{in}	5V@Bit Value : 1023
V_O	0V - 5V@Bit Value : 0 – 1023
Resistance, R_X=R_Y	10KΩ
Y-Axis	Value
Max Point	4.97V± 0.2V
Center Point	2.42V± 0.2V
Min Point	0.2V± 0.2V

Positive Range (Forward movement)	2.61V - 5V@Bit Range : 533 – 1023
Center Range (No movement)	2.2V – 2.6V@Bit Range : 532 – 450
Negative Range (Backward movement)	0V – 2.19V@Bit Range : 0 – 449
X-Axis	Value
Max Point	4.97V± 0.2V
Center Point	2.57V± 0.2V
Min Point	0.2V± 0.2V
Positive Range (Left movement)	2.71V - 5V@Bit Range : 553 – 1023
Center Range (No movement)	2.4V – 2.8V@Bit Range : 491 – 573
Negative Range (Right movement)	0V – 2.29V@Bit Range : 0 – 470

4.1.1.4 Flexible Force Sensor Resistor

The force sensors as shown in Figure 10 are placed at the tip of each arms of the robot where it is used to detect pressure when it is pressed to the ground. In this robot, the sensor controls its designated arm individually.[8] It is connected in pull-up setting where voltage source are connected at one end of the sensor and the other end connected to the Operational Amplifiers (OpAmp) as shown in Figure 11. When the sensor is pressed, it will generate a voltage difference between the sensor's terminals and the OpAmp will amplify the voltage. Then the microcontroller will detect the voltage difference and convert it into value 0 (for 0 Volt) until value 1023 (for 5 Volts). Then the microcontroller will compares the value with the limit which has been programmed and stops the designated arm from moving. The robot will start drag itself if any of the three conditions are met:

1. All sensors detect pressure.
2. All servos reach its angle limit.
3. Combination of pressure detection and servo angle limitation.

The sensors prevent the arms from excessive stress during dragging process because the energy used to drag the body is equally distributed between the arms. The sensors also act as surface level detection where the arm will stop if it detects surface level. This will enable the robot to move on uneven terrain.

Figure 10 : Force Sensor Resistor

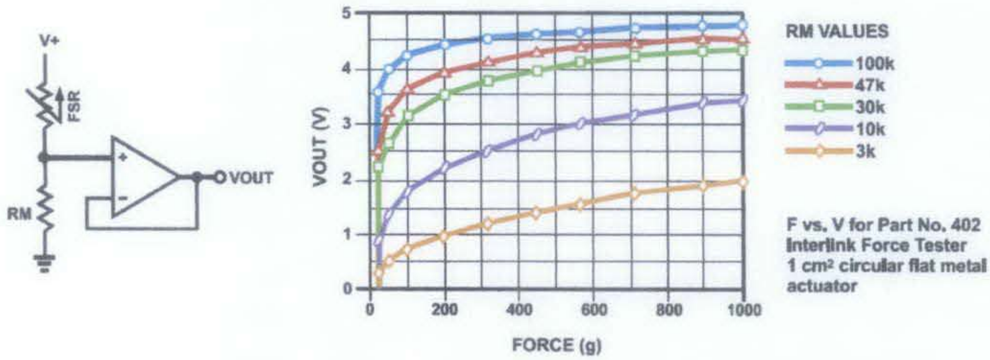

Figure 11 : FSR implementation schematic and the output graph.

4.1.1.5 Power Management System

The robot is powered by an external battery for mobility purposes. The components that need voltage supply are the Servos and the microcontroller. The servos use 6V while the microcontroller uses minimum voltage of 7V. A set of eight 1.2V batteries are connected to the input of two L7806 voltage regulators which are connected in parallel and three servos are connected in parallel which received power from the regulator output while another four servos are connected in parallel which received power from another regulator. This setting is used in order to reduce the power consumption by the servos thus increase the battery life. For the Microcontroller, it is powered by one 9V battery where it is enough to power the microcontroller for several hours. The complete schematic can be viewed in **Appendix B**.

4.1.2 Embedded Software Testing

To make the microcontroller to work, the brain of the device need to be programmed using programming software. The software used is Arduino-0018 as shown in Figure 12 is used to compile the source code and inject the codes into the microcontroller. This Atmel based Microcontroller uses C and C++ language to develop the program. During the development stage of the embedded software, there are several issues that need to overcome such as timing issues, number of analog inputs, multitasking (to operate six servos at the same time), speed control for the servos and many more. There are several versions that have been developed in order to overcome the issues. The flow diagrams of the source code for the robot are shown in **Appendix C**.

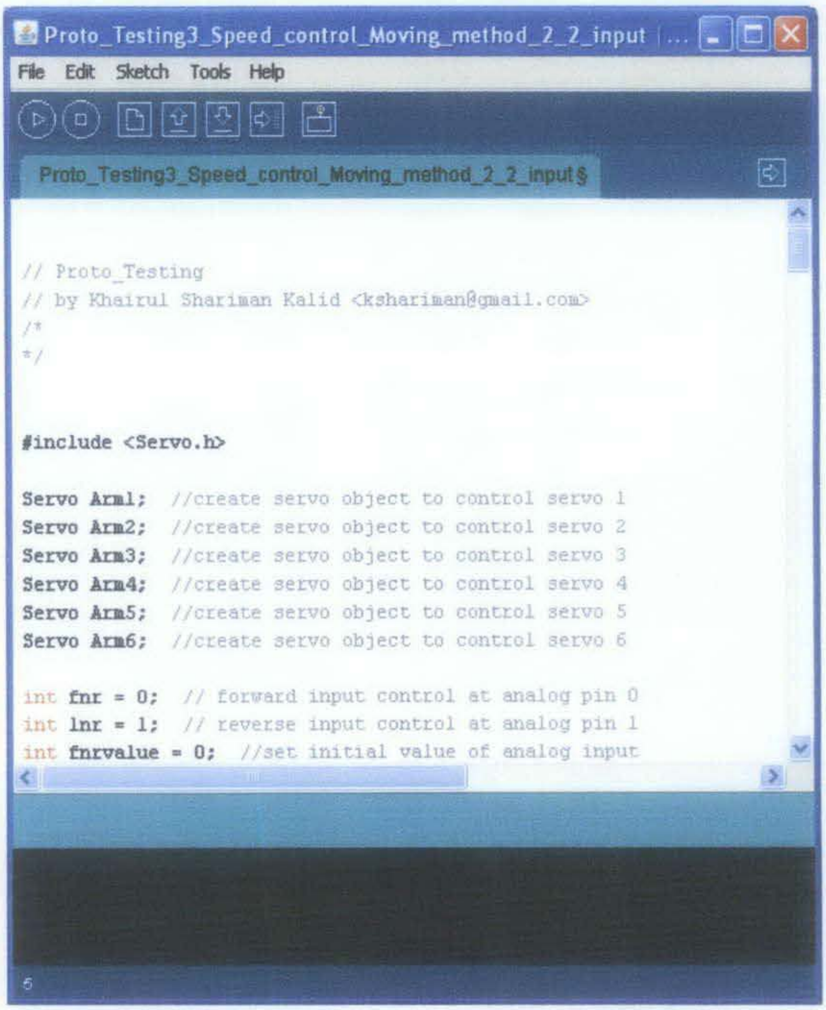

Figure 12: User interface of Arduino 0018

Figure 13 below shows the stages of developing the embedded coding and its issues:

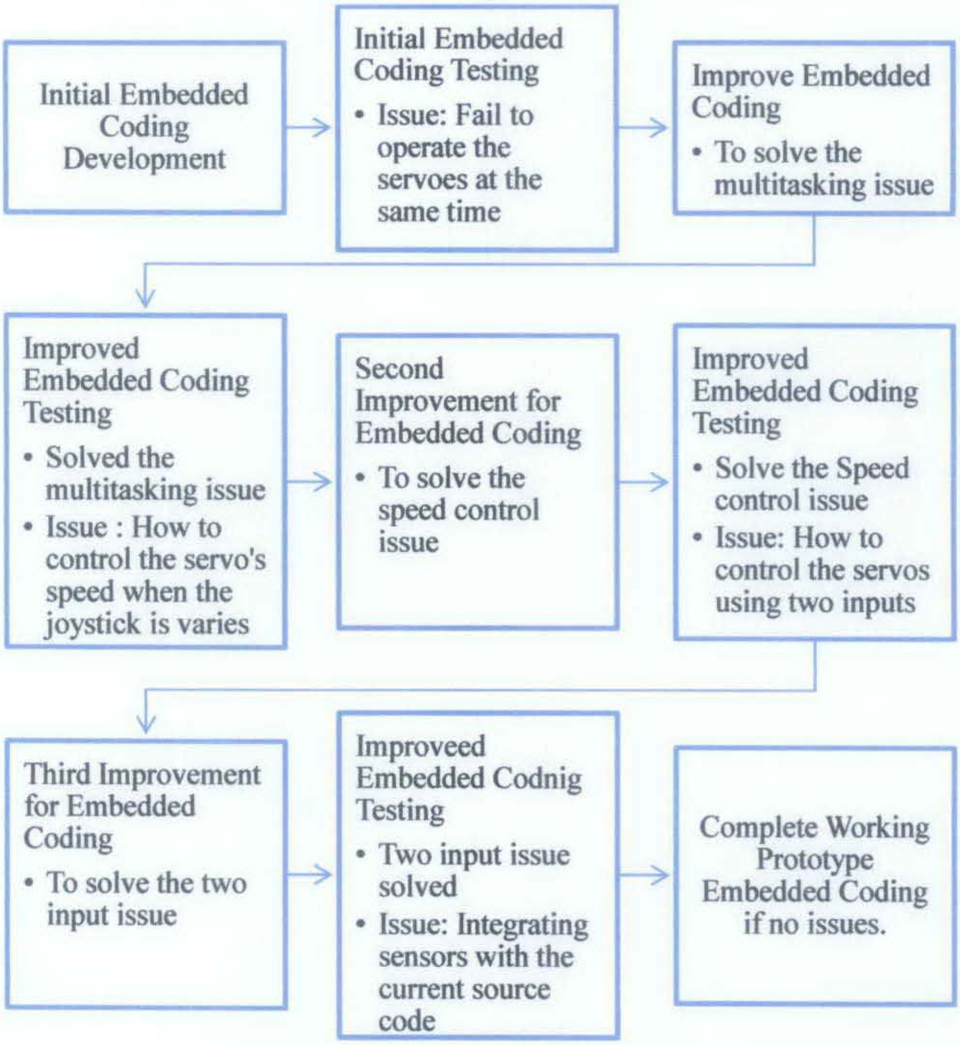

Figure 13: Development Process of Embedded Coding

All the issues mentioned in Figure 13 are solved by trial-and-error method where based on the results from tests conducted, the source code are modified until the desired results are obtained. The testing and modification are performed by observing the behavior of the robot. For example, in order to adjust the angle of the robot's arms, the source code for the servos is adjusted according to the desired angle. This method is also applied to the robot's locomotion setting.

4.1.3 Mechanical Design

There are two mechanical parts in TriBot that need to be design which are the arms and the body of the robot. For the arms, it uses servo bracket [7] which made from 1mm thick aluminum plate that has been bought specifically to fit servo motor. For the body, it is made out of thick plastic box with 75mm height and 150mm long and 190mm width. There are three joints in an arm where the first joint, J1 rotates on z-axis while second, J2 and third joint, J3 rotates on y-axis. Figure 14 shows the mechanical concept design for TriBot. The actual prototype pictures are shown in **Appendix D**.

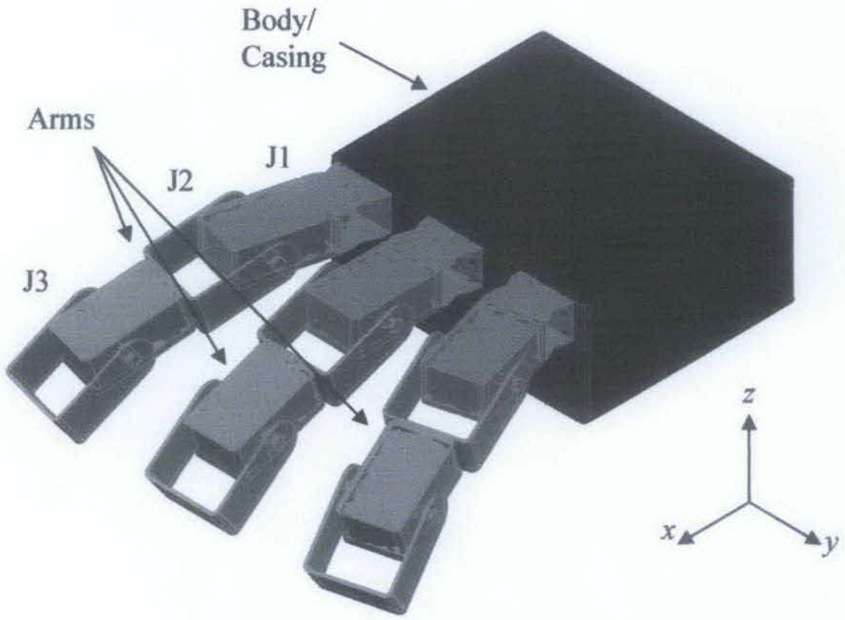

Figure 14: Mechanical Design Concept of TriBot

Previously the robot uses twisting method to turn left and right where third joint (J3) of the most left and most right arms rotate in opposite direction from each other when touching the surface. This turning method is not suitable to be applied on uneven surface. Thus, modifications need to be done in order for the robot to turn on uneven surface. Thus, a horizontal jointed bracket (J1) is introduced to each arm so that the arm can turn left and right smoothly. All three arms are linked together by aluminum plate in order to prevent the arms from hitting each other during the locomotion. The middle arm is connected to a servo by a strip of aluminum plate as the linkage between the arm and the servo which it will control the arms whether to turn left or right.

4.1.4 The Robot Locomotion

TriBot need to drag itself to move forward, reverse and also turning left and right. Previously, the movements of the arms are fixed with specified angle. Based on on-site testing, this method is not suitable for the robot to move on an uneven terrain. Therefore, force sensors are introduced and it is placed at the tip of the arms so that it will detect the uneven surfaces. Jointed bracket are placed in order for the robot to move left and right smoothly. All three arms are moving simultaneously so that the forces to drag its body are equally distributed to the arms. If the arms move one at a time, the servos that moving the arm are given excessive stress. Thus lessen the servo's life span. Figure 15 shows the process on how the robot moves. The flow diagram for the robot's movement can be viewed at **Appendix E**.

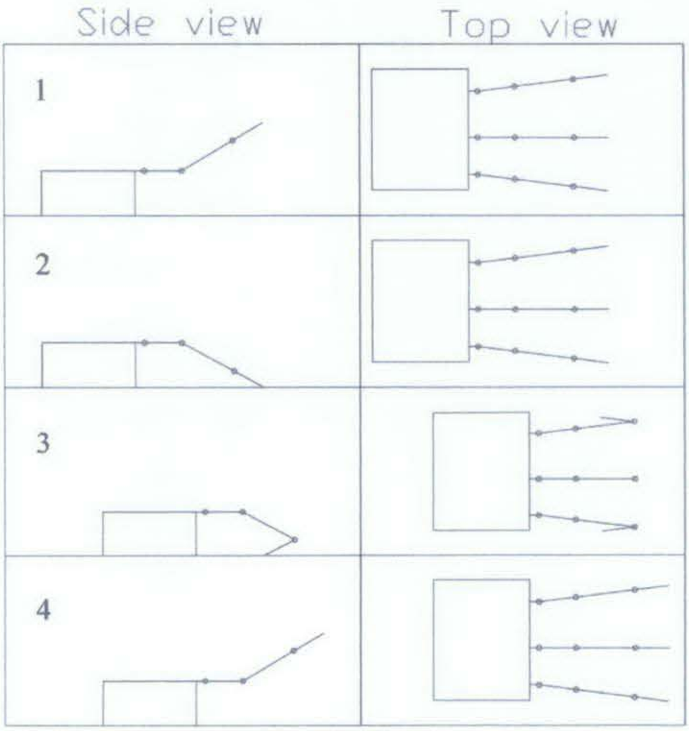

Figure 15: TriBot's forward/reverse locomotion

Basic principle of TriBot's movements is repetitions of forward motion and inverse motion of the arms. Forward motion is rotation a process of second joint (J2) reducing its angle until the arm reaches certain limit as shown in Figure 15, position 1 and position 2. Inverse motion is rotation of third joint (J3) from zero degrees to 125 degrees which will drag the robot forward then the J2 increases its angle back to initial position as shown in position 3 and position 4 in Figure 15.

All three arms move simultaneously for forward, reverse, left and right movement with combinations of forward and inverse motion. Based on Figure 15, the robot forward movement starts at position one where all the arms are aligned at angle of 160 degrees. The angle is reduced one degree at a time until it reaches zero degree which is the limit for the servo motors. If the sensors at the tip of the arms detect a pressure, then the designated arm will stop moving and stay at its current position while other will continue descending as shown in position two. If all sensors detect pressure or the angle reaches zero degree, the arms will start the inverse motion where the second joint of the arms will rotate 125 degree inward in order to drag the robot's body forward as shown in position three. Then all first joint of the arms rotate back to its initial position which is in position four. Figure 16 shows the sequence of TriBot's forward movement. Reverse movement is same as forward movement but in inverse order where it start from position four and end at position one. Figure 17 shows the sequence of TriBot's reverse movement.

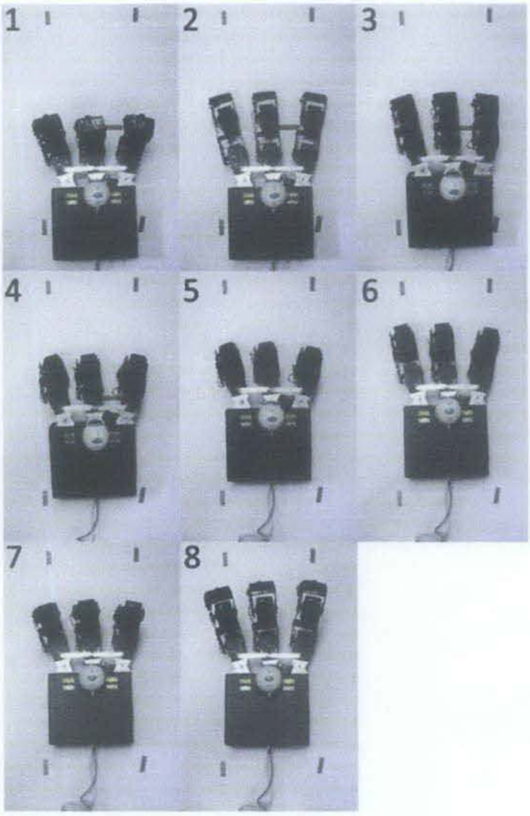

Figure 16: TriBot's Forward movement sequence

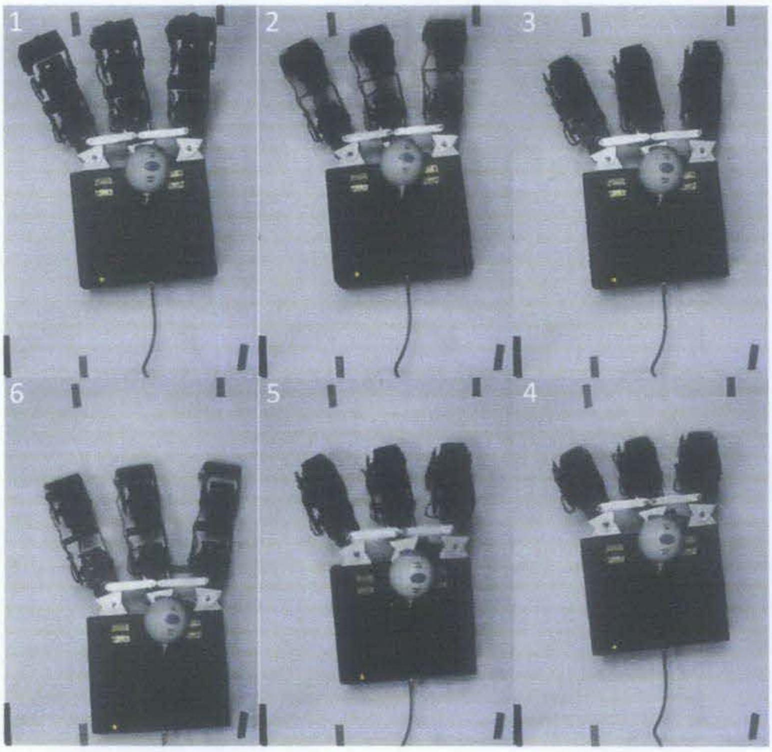

Figure 17: TriBot's Reverse movement sequence

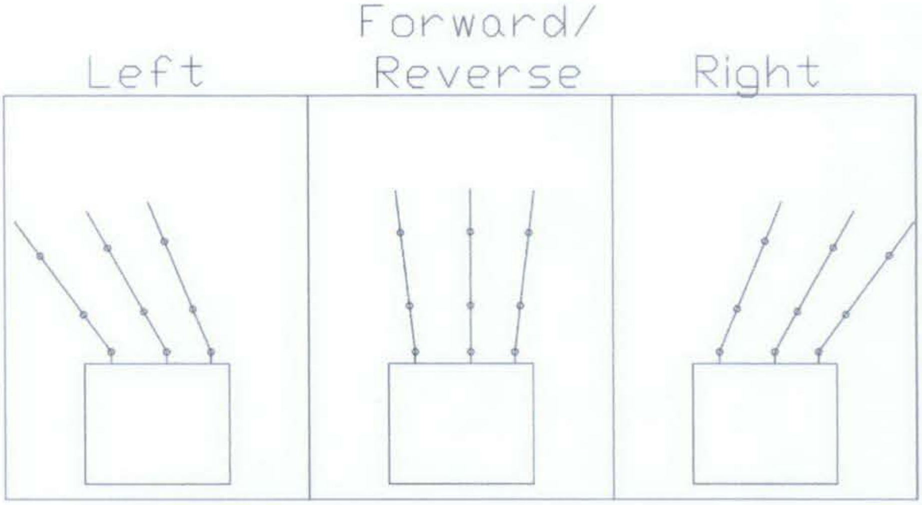

Figure 18 : TriBot's Left, Forward/Reverse and Right arm position.

Figure 18 shows the position of the robot when turning left and turning right. The algorithm for turning left and right is almost same as forward movement where it consists of forward motion and inverse motion. The only difference to the algorithm is that the angle of J3 is fixed with 90 degrees for both forward and inverse motions. In order for the robot to move left and right, extra servo motor which is the seventh servo motor are installed under the robot's arms and the center arm is linked to the servo motor. To turn the robot left, the servo rotates 180 degrees during forward motion and zero degrees during inverse motion. For turning right, the servo rotates 180 degrees during inverse motion and zero degrees during forward motion. Figure 19 shows the TriBot's left movement sequence. Same method is used for turning right, but the difference is that the orders of the movements are inversely to left movements. Figure 20 shows TriBot's sequence for turning right. The flow diagram for the robot's left and right movement can also be viewed at **Appendix E**.

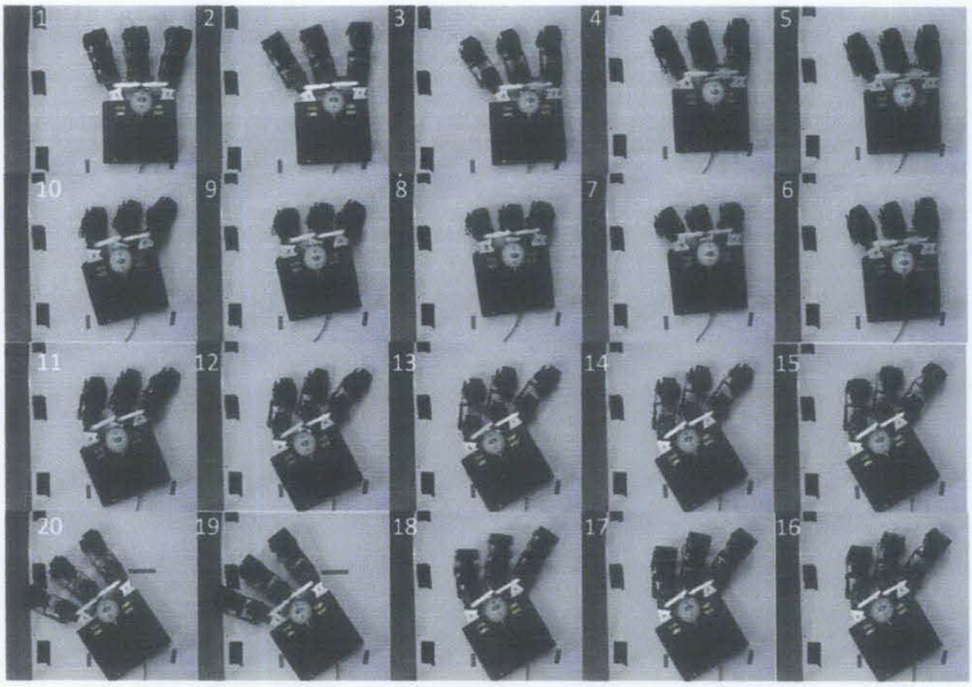

Figure 19: TriBot's Left movement sequence

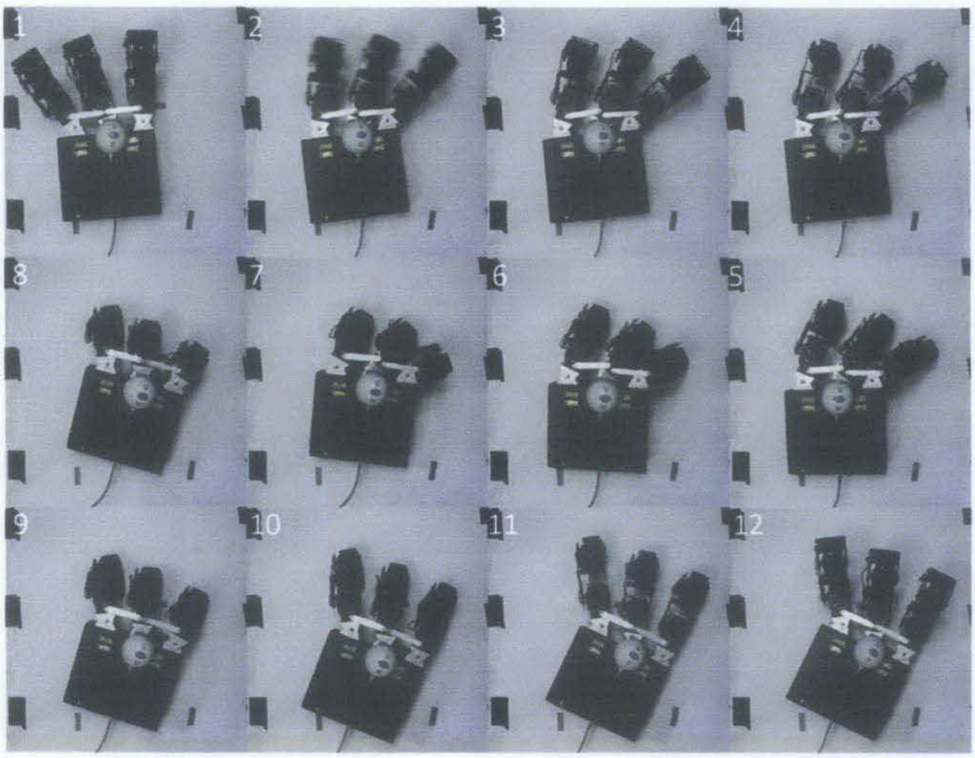

Figure 20: TriBot's Right movement sequence

4.2 Discussion

The testing of the robot locomotion need to be done on all aspect of search and rescue environments such as uneven surfaces, slope, smooth surface, hard surface, moving across an obstacle and many more. By introducing the force sensors to the robot, the movements on uneven surface are more effective because of the arms are capable to detect the unevenness of the surface. It is not a problem when navigating on the smooth and hard surfaces.

The problems for the robot to navigate are on slopes and moving on obstacles. This is because the 'Degree of Freedom' of the robot's arms are insufficient for the robot to move on certain height of obstacles and also the distance between obstacles. For slopes, it is bounded by certain degree of the slope angle. This is because there is less friction acted by the robot's body on the surface of the slope when the arms are in forward motion. During the forward motion, the arms will not have a contact with surface. Thus, reduce the friction between the body and the surface.

Further test need to be conducted in order to understand the behavior of the robot's locomotion on the slopes and also the behavior when moving across an obstacle. The maximum slope angle and the height of the obstacles can be obtained during the testing process.

CHAPTER 5
CONCLUSION AND RECOMMENDATION

This section will explain about the conclusion for this project and also the recommendation that can improve the performance of TriBot and also extra features that can be applied to TriBot.

5.1 Conclusion

In conclusion, it is shown that non-conventional locomotion have been achieved after integrating the robot with force sensors where TriBot can perform basic movement which is forward, reverse, turning left and turning right on a flat smooth and rough surface.This basic movements are achieved by integrating all three areas of engineering which is Electrical and Electronic, Embedded Software and Mechanical Design into one prototype which is TriBot itself. Force sensors has been attached on the tip of the arms of the TriBot so that it can navigate on any surface with fixed height, fixed arm length and also one source code for all surfaces.

5.2 Recommendation

It is recommended to have further improvement on the TriBot movement algorithm for climbing motion. It is based on tests that have been done on standard normal stairs. This is because, with non-conventional locomotion for climbing purposes are different with moving on flat surface and uneven surface. The differences are on the height of the surface level and the position of the arms during climbing motion. A set of small tires are recommended to be installed to the body of the robot so that the robot can move smoothly during locomotion. When the robot drag itself forward, the contact of the robot body with the surface will cause high friction. When a set of tires are installed to the robot, it will reduce the contact between the robot and the surface. Thus, reduce the friction and smoothen the robot movement. It is also recommended to add extra features to the TriBot to widen its application in the real environment application. Extra features such as camera, microphone and speakers are recommended to install to the robot which will make TriBot applicable for search-and-rescue mission as mentioned earlier and even in military mission.

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Appendix A

ARDUINO DUEMILANOVA SCHEMATIC

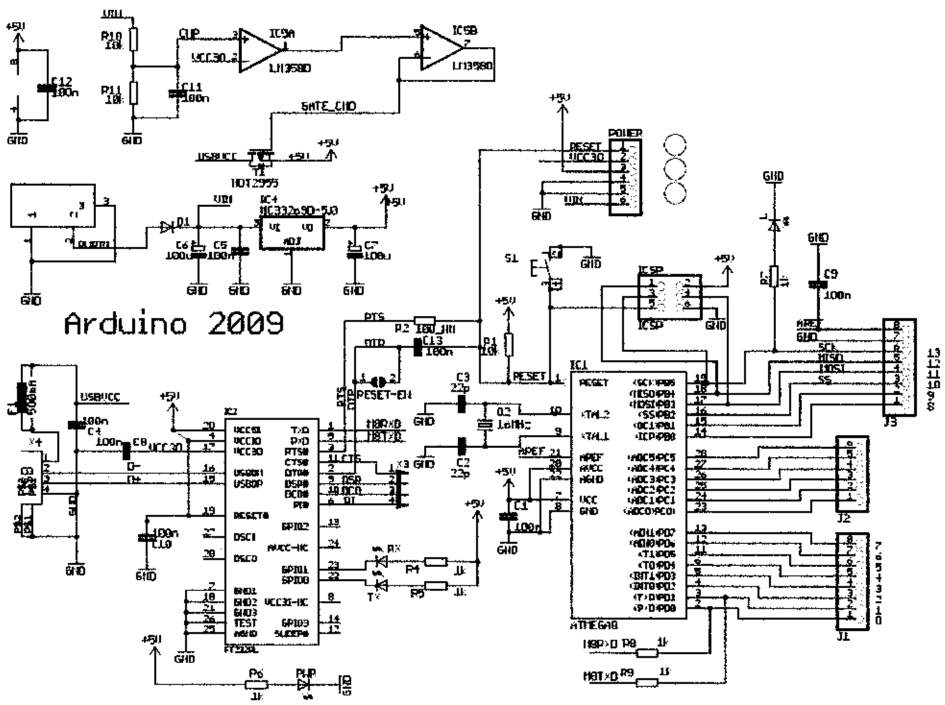

Figure 21 : Arduino Duemilanove Schematic

Appendix B

TRIBOT COMPLETE SCHEMATIC

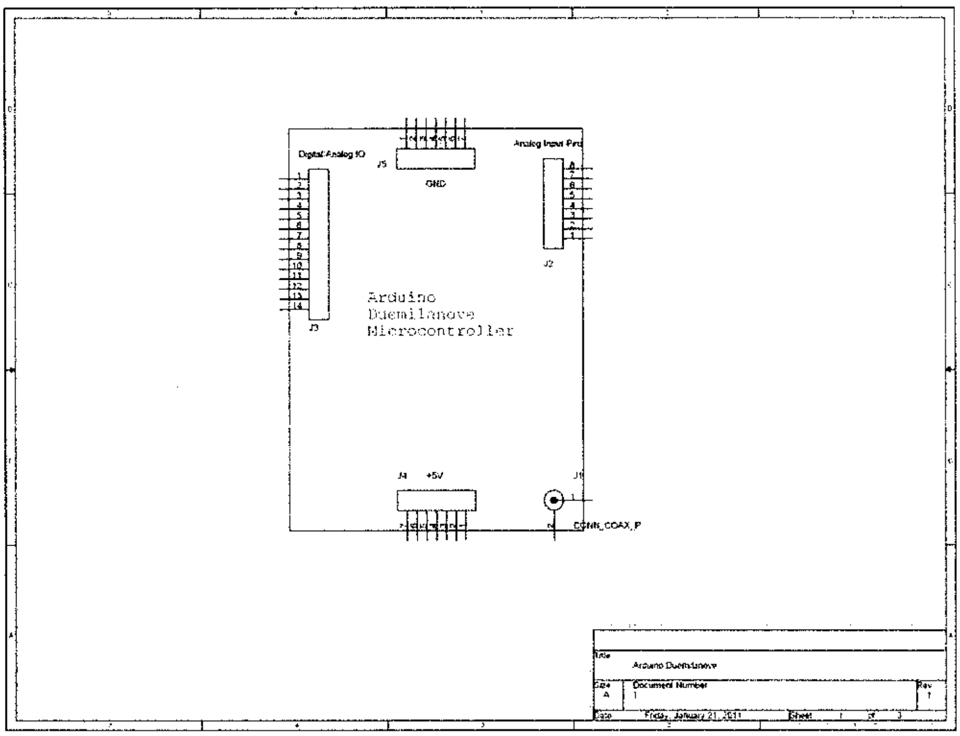

Figure 22 : Arduino Duemilanove Pin configuration

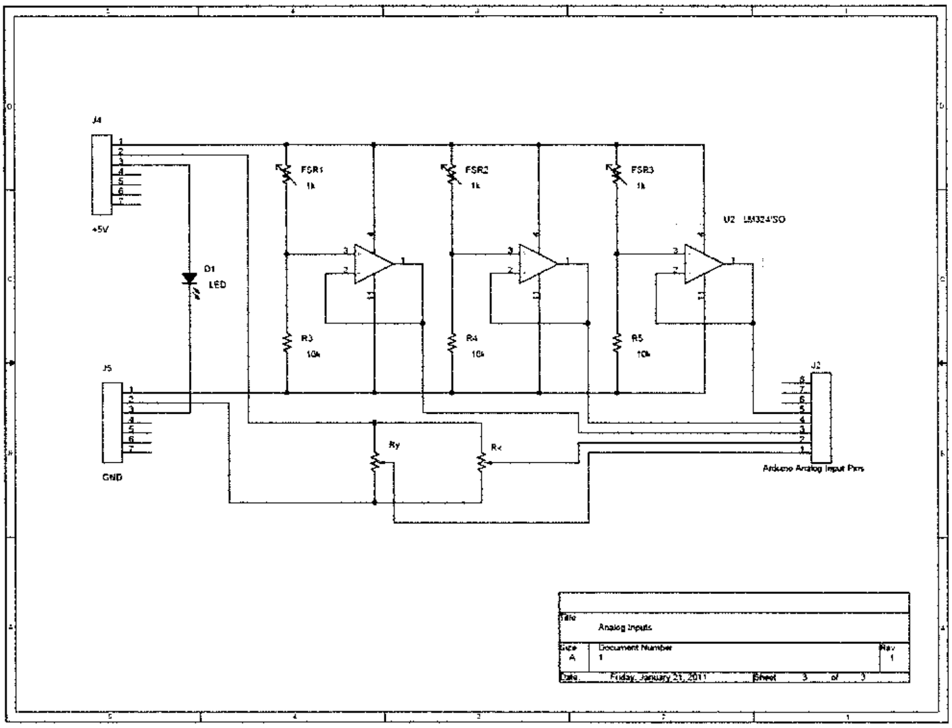

Figure 23 : TriBot's input configuration

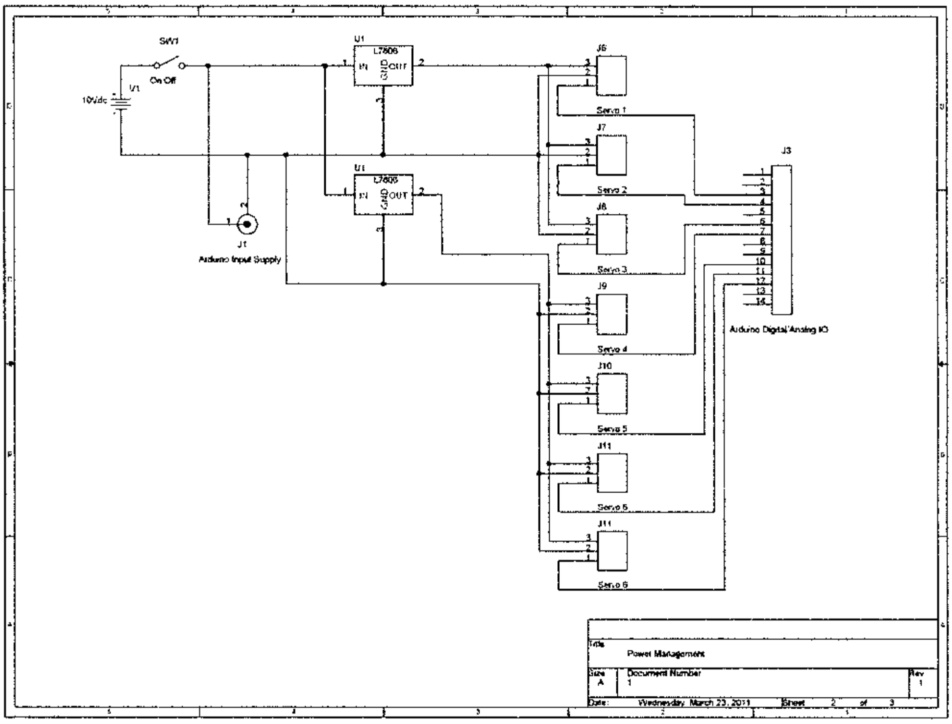

Figure 24: TriBot's Power management and Output configuration

Appendix C

FLOW DIAGRAM OF THE SOURCE CODE

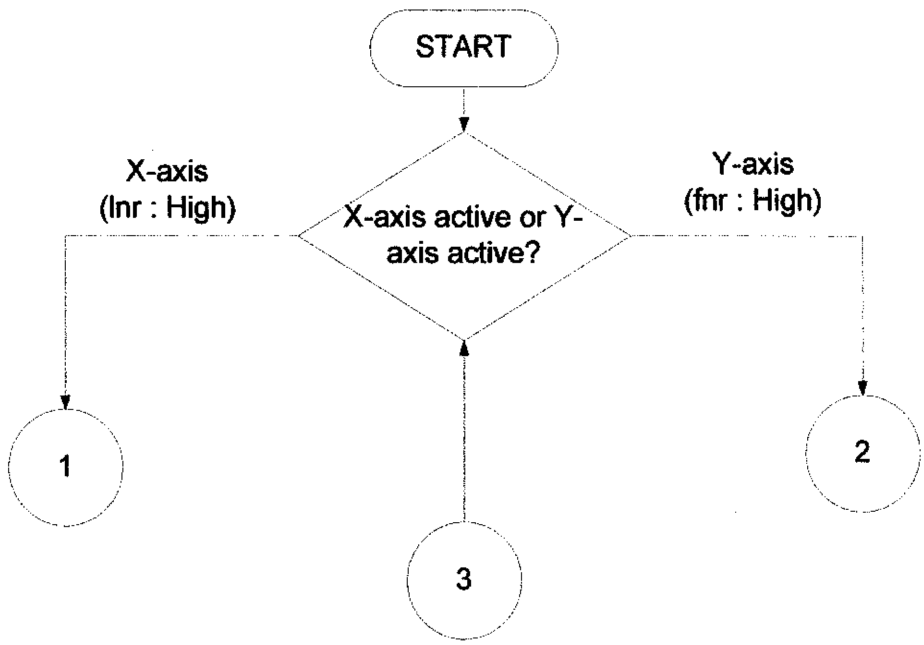

Figure 25 : The flow diagram for selecting forward/reverse or left/right.

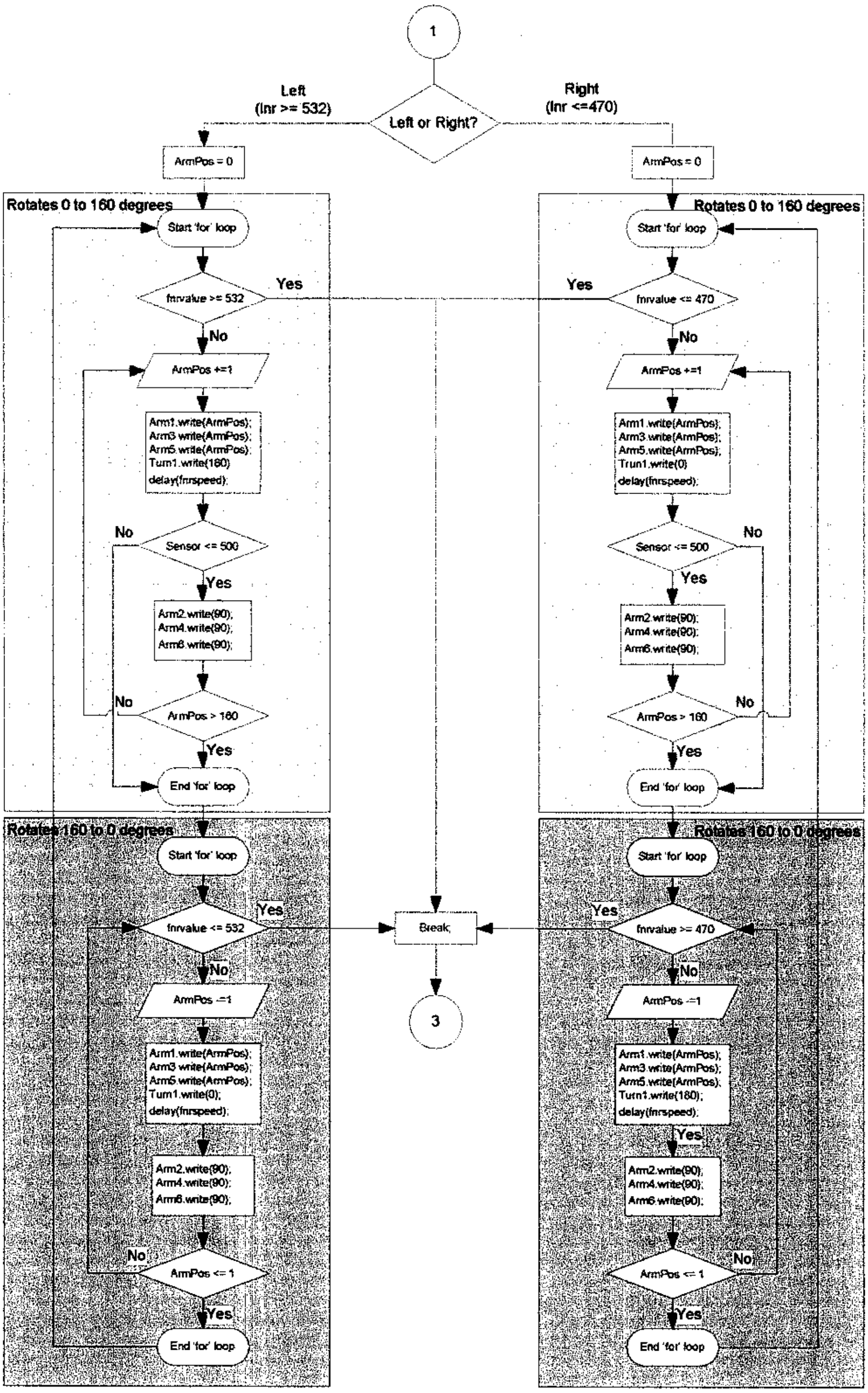

Figure 26: The flow diagram for left and right movements.

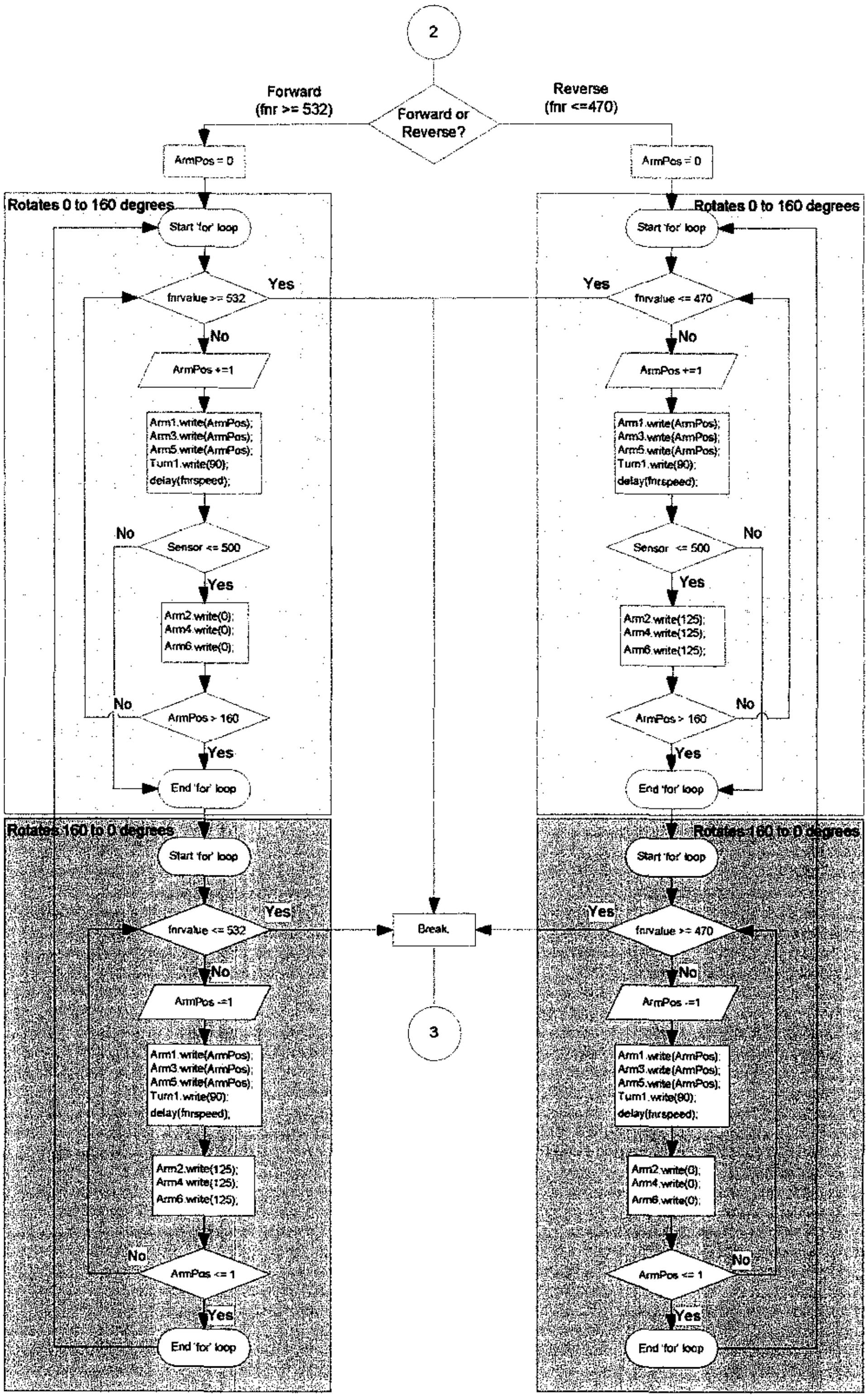

Figure 27 : The flow diagram for forward and reverse movement.

Appendix D

TRIBOT PICTURES

Figure 28: TriBot previous version

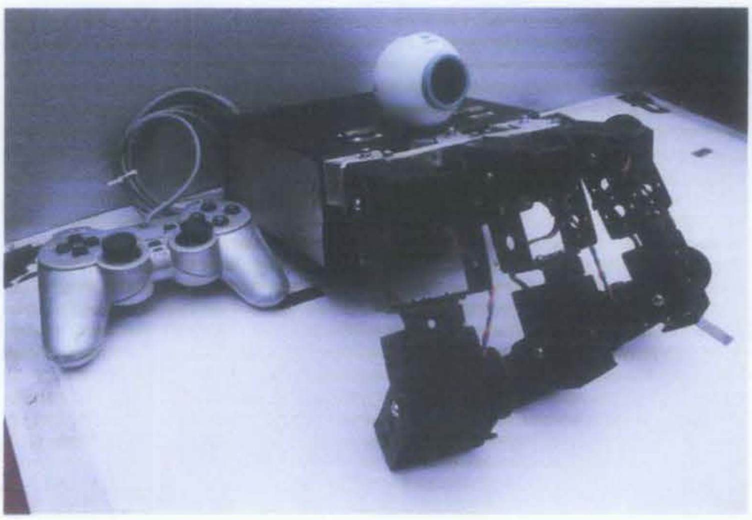

Figure 29: TriBot Final Prototype

Appendix E

FLOW DIAGRAM OF TRIBOT'S MOVEMENT

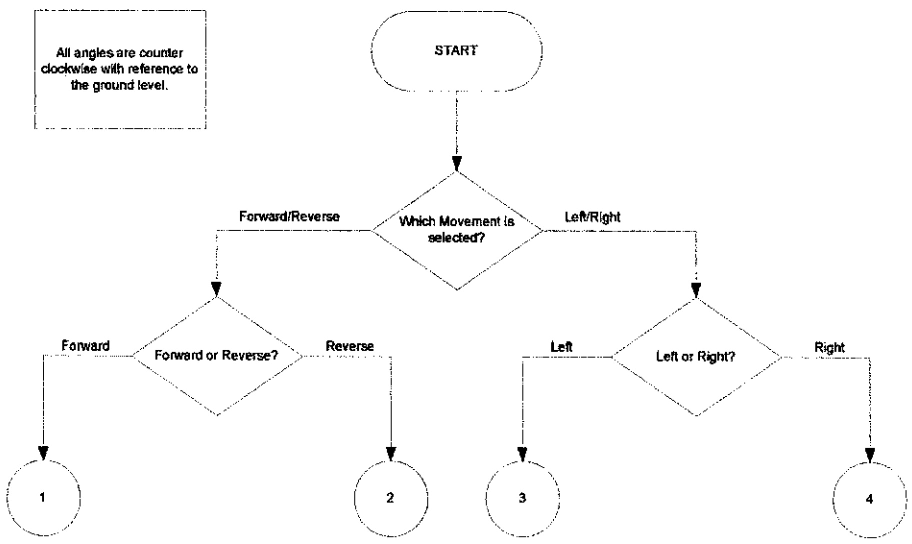

Figure 30: Flow of Movements Selection

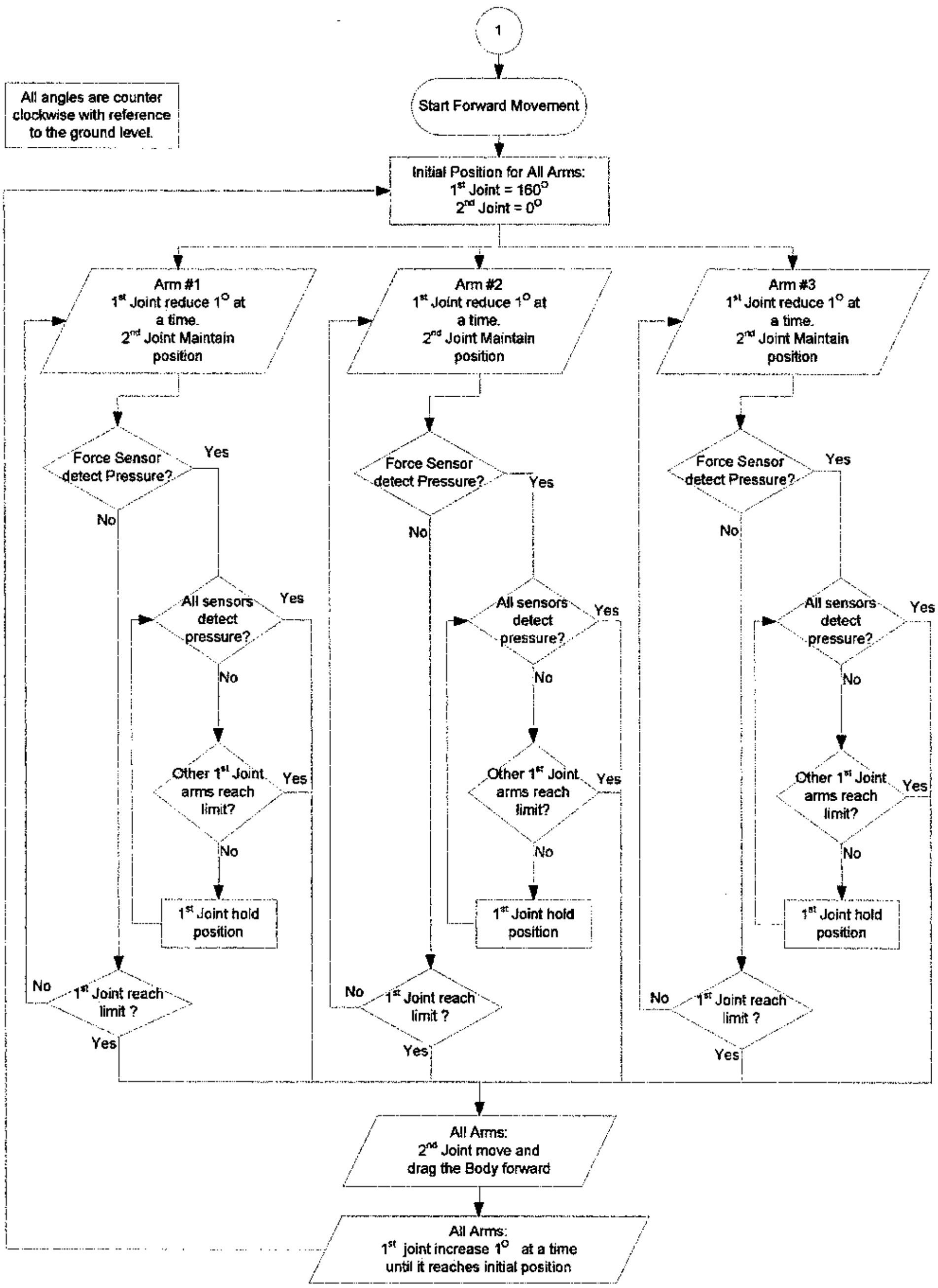

Figure 31: Forward movement flow diagram

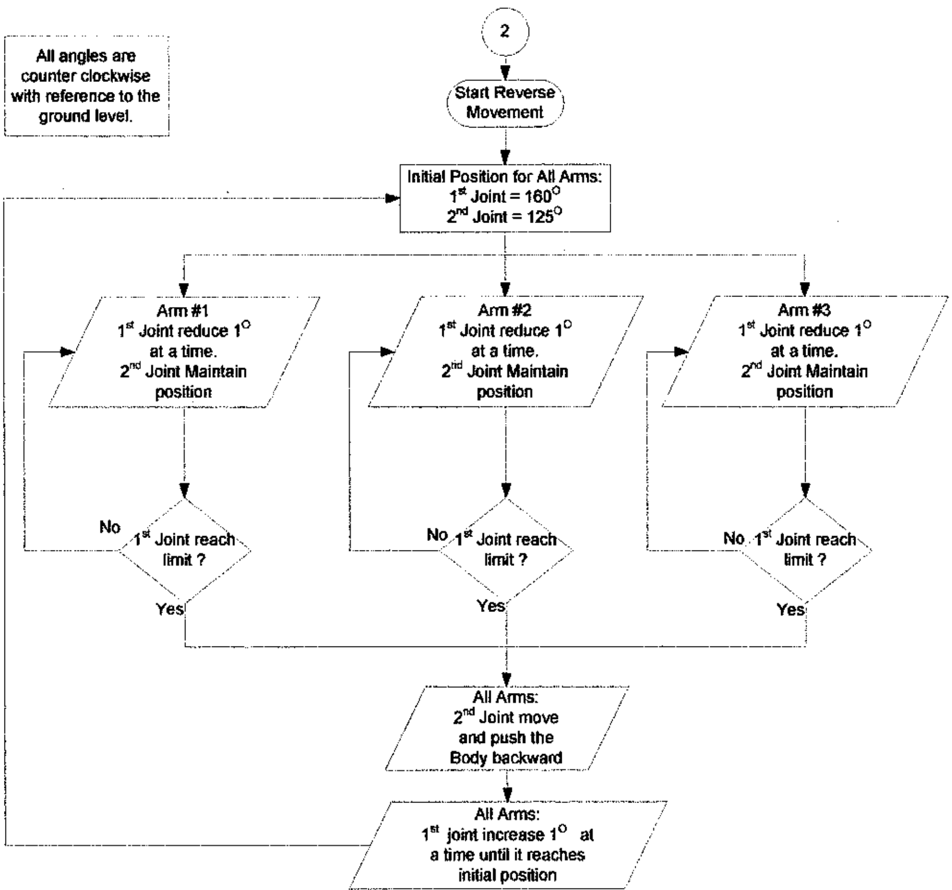

Figure 32: Reverse movement flow diagram

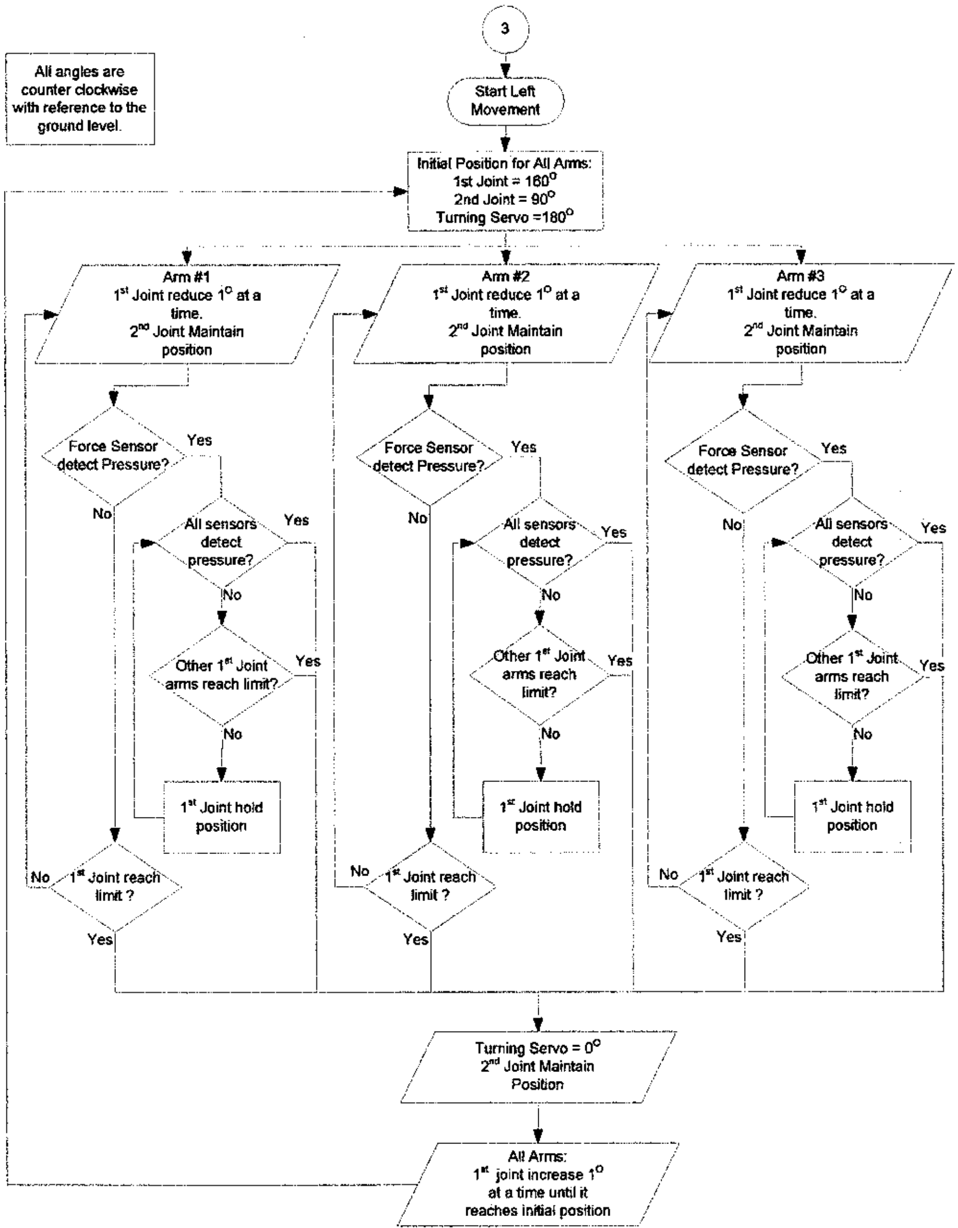

Figure 33: Left movement flow diagram

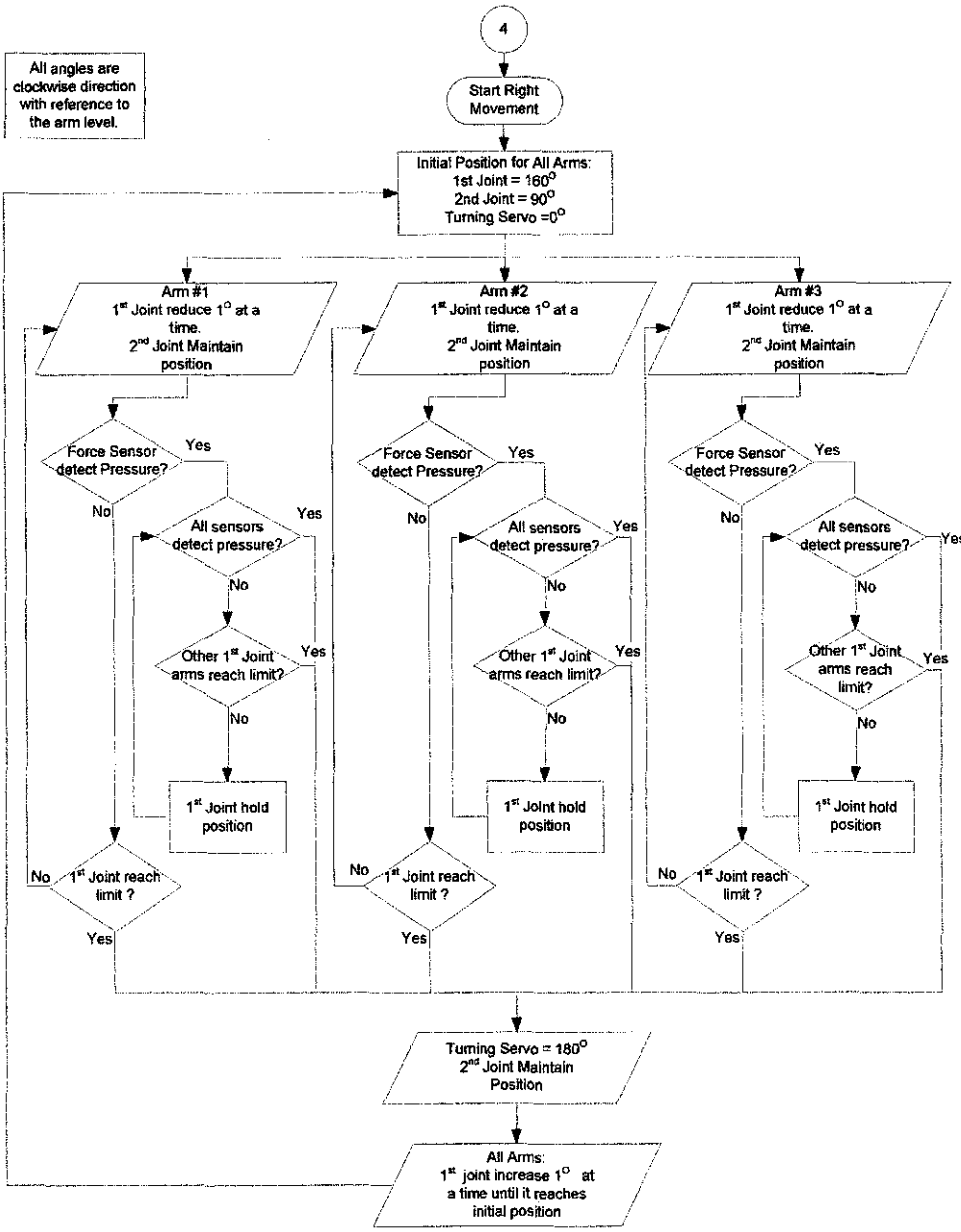

Figure 34: Right movement flow diagram